

**APPLICATION IN
THE UNITED STATES
PATENT AND TRADEMARK OFFICE**

**FOR
HERMETIC SEAL ON METALLIZED FIBER OPTICS**

INVENTORS:

**Matthew W. Holt
103 Oakview Dr.
Elon, NC 27244
U.S. Citizen**

**Frederick Paul Gehrke
1810 Swannanoa Drive
Greensboro, NC 27410
U.S. Citizen**

**George W. Walker, III
2655 Piney Grove Rd.
Kernersville, NC 27284
U.S. citizen**

**Howrey Simon Arnold & White, LLP
301 Ravenswood Avenue
Box 34
Menlo Park, CA 94025
(650) 463-8109**

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Hermetic Seal on Metallized Fiber Optics

This application claims priority to provisional patent application Serial No. 60/483,256, entitled "Epoxy Seal on Metallized Fiber Optics" by Matthew W. Holt, Fred P. Gehrke and George W. Walker, filed on June 27, 2003, which is incorporated herein by reference.

Background of the Invention

As data transmission bandwidth demands increase, fiber optic cables are in increasing use in many applications. One such application of high importance is transmission of data by undersea cables.

In this setting, the pressures on electrical and/or optical connectors and cabling pose a threat to the integrity of the transmission cables. Junction regions are particularly vulnerable, such as where a high-pressure region is coupled to a low-pressure region in an undersea environment.

Some systems currently in use include a "multi-gland" fiber seal to block the passage of gases and fluids. Such seals generally have to be hand crafted and formed in matched groups with tight specifications, and are designed primarily to prevent water ingress in the event of a cable breach. Gland seals are somewhat limited in their ability to tolerate high pressure.

There is a need for a seal for undersea cables, including cable junctions, that does not need to be hand-made and is tolerant of variations in the manufacture process without compromising integrity. In particular, there is a need for such a seal that protects against the passage of both gases and liquids, and that survives high-pressure environments intact.

An advantage of the epoxy seal vis-à-vis prior sealing arrangements, such as multi-gland seals, is the ability of the seal to operate while at pressure with an optical loss

of less than approximately 0.05 db. This can be achieved by the bonding of the optical fibers plating to the epoxy material, minimizing or preventing possible extrusions at high pressure, which could cause damage to the optical path.

5 Summary of the Invention

The present invention uses optical fibers with metallization applied directly to the optical fiber (i.e. with no intervening cladding or coating). The metallized optical fiber is cast in high-strength epoxy to create a multiple-fiber seal capable of surviving extremely high pressures (more than 10,000 psi) and long-term exposure to hydrostatic loads with
10 minimal diminishment in performance of the optical fiber. The invention is applicable to other types of cables, such as metal conductive cables or multiconductor cables.

Conductive tubes are positioned surrounding the sealed fiber optic cable, both providing pressure protection and forming a continuous conductive path through which power may be supplied to electronics served by the cable. An insulating polyethylene
15 outer sleeve may be positioned around the conductive tubes.

The invention also includes a method of sealing fiber optic cables, including removing, as necessary, any cladding or coating on the optical fibers, metallizing at least a portion of the area where the coating was removed, and applying a high-strength sealing or bonding agent such as epoxy to that area.

20 The invention also includes a data transmission system utilizing a sealed fiber optic cable as described, with at least one electronic module including communications equipment in a relatively low-pressure environment coupled to the fiber optic cable which is positioned in a relatively high-pressure environment.

25 Brief Description of the Drawings

Figure 1 is a sectional view of a junction region for fiber optic cables including a seal according to the invention.

Figures 2-4 illustrate stages in a process of stripping and metallizing a portion of fiber optic cable.

Figure 5 is a perspective of the junction region shown in Figure 1.

Figure 6 is a sectional view of a junction region for fiber optic cables including a
5 pressure housing.

Figure 6A is an expanded view of a portion of Figure 6.

Figure 7 is a view of an undersea environment in which embodiments of the invention may be used.

10 Detailed Description

In Figure 1, a junction region 10 is shown, wherein one or multiple fiber optic cables, or other types of cables, wires, lines, etc., pass from a region 20 to a region 30. In the embodiment shown in Figure 1, region 20 is a relatively low-pressure region, and region 30 is a relatively high-pressure region. For example, region 30 may be a region on
15 an ocean floor, subject to the high pressures of that environment, while region 20 may be part of an undersea electronics module or station, which is filled with nitrogen gas and protected from the high water pressure outside the module.

As used herein, the term "cable" may refer to a single optical fiber, multiple optical fibers, one or more wires, conductors, communications cables, or other similar
20 structures to which a seal may need to be applied.

The "low" and "high" pressures are relative, and either may be less or greater than, e.g., standard atmospheric pressure. There need not even be a pressure differential between regions 20 and 30, but rather this may be a transition from one environment to another where it is desired that fluids (e.g. liquids or gases) or other materials should not
25 pass between the environments.

In the embodiment of Figure 1 (and Figure 5), four cables 40, 50, 60 and 70 pass between regions 20 and 30. Other numbers of cables will be suitable for use in the

invention. In this examples, the cables 40-70 are optical fibers, each with a silica or other suitable core 42, 52, etc. (see Figures 1 and 2-4), and each with a conventional cladding layer, coating or buffer material 44, 54, 64 and 74, respectively. This coating may be acrylate or another suitable coating.

5 Region 70 in Figure 1 (and see Figure 3) depicts a length of the fibers 40-70 where the coating 44-74 has been removed to expose the silica core 42-72. This may be done by laser ablation, mechanical removal, chemical removal or other suitable processes that will strip off the coating. A laser process is less likely to result in damage to the fiber optic core than a mechanical process. Thus, an initial step of removing, as necessary, at
10 least some of a layer over the cable core may be regarded as removing nothing (if a suitable material is already presented to which a bonding layer such as epoxy is exposed) or removing a sufficient amount (either none or a positive amount) of the overlayer such that a surface is exposed to which a bonding layer (e.g. metallization) may be applied.

 The coating is substantially entirely removed from the silica core. A suitable
15 process for stripping the coating can be carried out by, for example, using the laser stripping process of Resonetics, Inc. of Nashua, New Hampshire, which is capable of mid-span optical fiber coating removal with minimal degradation of the silica core.

 The region 70 where the core is exposed is directly metallized using, for example, a chemical vapor deposition of chromium (or chrome), nickel and gold (or some
20 combination of one or more of these), forming a metallic bonding layer (e.g. layer 46 in Figure 4) around the core. Other metals may be appropriate for the bonding layer, as long as epoxy bonds to the metal(s) sufficiently to form a seal with a desired level of pressure resistance. Other (nonmetallic or metallic) materials may be suitable for forming the bonding layer.

25 The metallization (or plating) is "directly" on the fiber core in the sense that there is substantially no intervening acrylate or other coating for at least a portion of the

metallized region, though other materials to which the epoxy or other sealant may bond could be present.

The plating creates a substrate to which the epoxy can bond, thereby eliminating or minimizing a path along the outside of the fiber where fluid would otherwise be able to travel through the overmolded volume of fiber. Removal of the acrylate coating also eliminates a fluid path, either permeating the acrylate or through flaws or cracks therein.

Region 70 may be about a half an inch (or 1-2 centimeters) long, and in general may be made sufficiently long for a given environment such that the sealing effect along the length of the completed seal meets some predetermined criterion, such as a maximum leak rate.

The optical fibers 40-70 may be bundled together (see Figures 1 and 5) to pass into region 20. As shown in Figure 7, this region may include an electronics module or box 700, or may be some other region different from region 30, as discussed above. The module 700 may include one or more repeaters, multiplexers, and/or other appropriate equipment 770, such as communications or data transmission equipment.

During assembly of the junction region 10 shown in Figure 1, a fiber guide/strain relief 80 may be positioned over a portion of the cables 40-70 near where they are bundled more closely together. The strain relief 80 may be a flexible Teflon® or other tube, and may be filled with an epoxy 90 (e.g. an ultraviolet-curable epoxy) or other bonding agent that assists in holding the tube 80 in position over the area where they come together, to help prevent undue bending or breakage in that area.

The fiber region 70, and optionally also the regions of the fibers extending somewhat beyond (to the left and right from the point of view of Figure 1), are then placed into a mold, and cast with an epoxy for an amount of time sufficient that it will adhere or bond to at least a portion of the metallized area of the fiber, creating a seal around each individual fiber and eliminating the diffusion/leak path for helium and sea water. The epoxy (which may also be UV-curable) or other pressure-resistant bonding

agent 100 is thus applied to a length of the fibers 40-70 between the strain relief (if present) or the region 20 (if no strain relief is used) and the region 30, as illustrated in Figure 1.

Epoxy bonds well to the metallization in the region 70, and when hardened forms a durable coupling between the regions 20 and 30, thereby providing a seal around the fibers against the passage of fluids even at very high pressure differentials. This structure avoids the cracking in the coatings and resulting formation of fluid passageways that can occur if the coatings are not removed before application of the epoxy. The metallization forms a good bond or adhesion to the silica core, and the epoxy bonds well with the metallization, thus substantially eliminating weak spots in the pressure protection.

Figure 5 is an exterior perspective view of a structure as described with respect to Figure 1.

Figure 6 is a sectional view of the structure shown in Figures 1 and 5, illustrating an embodiment where the epoxy-sealed structure is used in a position marking the transition between a very high-pressure setting and a lower-pressure setting, such as the transition between an undersea environment and an electronics module 700 (see Figure 7). The optical fibers 40-70 are inserted through a conductive or voltage-carrying pressure housing 110, which may be a substantially rigid metal tube, such as made out of beryllium-copper, and thus pass through passageway 120 and into a tube 130 made of copper (or another suitable material such as a conductive material that resists pressure and corrosion). The tube 130 may itself be at least partially enclosed by a sleeve of an insulating material, such as polyethylene tube 140.

To affix the tube 130 to the housing 110, a brazed alloy fillet 150 is applied circumferentially around the tube 130.

O-ring seals 160 and 170 may be positioned within circumferential grooves 180 and 190 formed on an inner surface 200 of the housing 110, to prevent passage of fluids through the interior cylindrical cavity defined by surface 200. Thus, in this embodiment,

the epoxy seal 100 has an outer surface that closely matches the shape of inner surface 200, e.g. a cylindrical shape (whose cross-section may be circular or some other shape), so that the O-rings can provide a good seal against fluid passage.

5 A retainer ring 210 is positioned within a groove 220 in the housing 110 (see expanded view of Figure 6A) to retain the assembly including the epoxy seal 100 within the housing 110 interior cavity. The fibers 40-70 pass through an opening (not separately shown) in the retainer ring 210 and through a passageway 230, and thence into a substantially rigid fiber housing or tube 240. A housing 250 (which may be of beryllium-copper or some other conductor) surrounds the optical fibers and is tack-welded to the
10 housing 110 at points of contact between the two, in effect forming a single housing including housings 110 and 250 that encloses the epoxy seal junction region.

The tube 240 is affixed to the housing 250 by brazed alloy fillet 260, which extends circumferentially around the tube 240. An insulating polyethylene sleeve or tube 270 may be provided around the tube 240 in the undersea (or other aqueous or fluid)
15 environment. Thus, the entire assembly shown in Figure 6 (except for the module 700) may in this embodiment be substantially circular in cross-section, or at least include no sharp angles that would make sealing difficult or less effective.

The housing 110, in cooperation with the tubes 140 and 260, in some embodiments forms a continuous conductive path that may be used to carry a current to
20 devices along the fiber optic cable, for instance to power electronics within the housing 700.

The combined housing 110-250 includes a portion 280 that extends into the generally cylindrical cavity formed by the inner surface 200, and abuts a sealing O-ring 290 positioned within a circumferential groove 300, similar to the position of with O-rings 160-170 within grooves 180-190, thus preventing or minimizing fluid passage
25 within the cavity past portion 280.

A suitable seal 710, such as a Bridgeman seal, may be provided where the tubes 130 and 140 pass into the module 700 (see Figures 6 and 7), and an overall protective sleeve tube 720 may be provided over the junction structure as illustrated, and may be formed of an insulating material such as polyethylene. Thus, the sleeves 140, 270 and
5 720 may be regarded as three separate sleeves (and may be applied at different times), but when complete may function as a single insulating sleeve.

As shown in Figure 7, an additional such sealed junction region may be coupled to the electronics module 700 to continue passage of the cable beyond the module. This will be a common configuration in a situation where the module 700 is not a terminal
10 module or station, e.g. where it is a repeater in a communication system. Thus, tube 740, tube 730, tube 750 and seal 760 correspond to tubes 270, 720 and 140 and seal 710, respectively, and include a structure similar to that shown in Figure 6, to form a junction region extending from module 700 back into the undersea environment, in which the cable extends to the next repeater station or other electronic equipment.

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A structure with features of the above exemplary implementations of the invention have been subjected to a helium leak test (at around 10,000 psi), which resulted in a leak rate of less than 1×10^{-9} std cc/sec Helium, and long-term exposure to hydrostatic loads to 12,000 psi with an optical loss less than 0.05 db during operation.

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An epoxy seal according to the above description thus creates a hermetic seal around the voltage and optical path. This allows undersea systems pressure vessels to be high-pressure helium leak-tested after welding to verify the welds' integrity as well as preventing water or other fluid ingress into the vessel while deployed. The seal also helps maintain the nitrogen pressure in the vessel (module) during the system's storage
25 and in use conditions.

In an optical seal (i.e. sealing of an optical fiber or cable), this sealing method can eliminate or substantially reduce the cost and process times that would otherwise be

involved using a multi-gland fiber seal mentioned above. The present invention provides sealing at higher pressures than gland seals, at least in part by minimizing or eliminating the fluid path available along the acrylate coating on the optical fiber, which forms a path for fluid ingress into the pressure vessel. Removal of the acrylate coating and metallizing the optical fiber directly, and then applying an epoxy seal, leads to much better sealing properties.